ESPC Common Model Architecture

Earth System Modeling Framework (ESMF)
Software and Application Development
Cecelia Deluca
NESII/CIRES/NOAA Earth System Research Laboratory
325 Broadway, Boulder 80305-337
Phone: (303) 497-3604 Email: cecelia.deluca@noaa.gov

Melinda Peng
Marine Meteorology Division, Code 7532
Naval Research Laboratory
Monterey, CA 93943
Phone: (831) 656-4704 Fax: (831) 656-4769 Email: melinda.peng@nrlmry.navy.mil

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LONG-TERM GOALS

To expedite the development of numerical weather prediction (NWP) systems, a national partnership National Unified Operational Prediction Capability (NUOPC) was established between NOAA and Navy to develop common software architecture for easy and efficient interoperability. The overarching goal of NUOPC is to accelerate the rate of improvement in the US National environmental prediction capability, focusing initially on the global model enterprise. Improvements in prediction capability are expected to result in better environmental situation awareness, severe weather warnings (hurricanes, tornadoes, snow storms), better cost avoidance for weather sensitive industries (agriculture, transportation, utilities, and defense), and better informed decision making for industry, defense and the general public. These goals will be achieved through model development under a common model architecture and other software-related standards in this project.

OBJECTIVES

NUOPC proposes to accelerate improvement of our national prediction capability in the following ways: (1) Implementing a global atmospheric multi-model ensemble system designed to enhance predictive capability and to provide probabilistic prediction for severe weather events; (2) Clearly articulating operational requirements and articulating a corresponding National research agenda; (3) Sharing the development efforts and promote collaborations of numerical weather prediction (NWP) systems among the operational agencies; (4) Accelerating the transition of new technology into the operational centers; (5) Designing requirements and standards of future NWP systems, (6) Accelerating the development and transition of Navy global ensemble prediction system and its participation in the national multi-model ensemble system, and, (7) Implementing ways to enhance broad community participation in addressing the National research agenda.

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APPROACH

This project will support improvements and optimizations to the Earth System Modeling Framework (ESMF) library and NUOPC standard by NOAA/ESRL for an efficient coupling capability. ESMF is infrastructure for building and coupling weather, climate, coastal, and other applications. The NUOPC Layer software is a small set of interfaces that provide templates and conventions that standardize ESMF implementation and increase the interoperability of components. The improved system will be adopted and tested by NRL for the Navy coupled system. The ESMF development team will provide support for the implementation.

WORK COMPLETED

The most significant achievement during FY14 was the completion of a production version and public release of the NUOPC Layer software. Like ESMF, the NUOPC Layer is now fundamentally complete and major changes to the design and interface are not anticipated in the future. However, both ESMF and the NUOPC Layer will require the addition of capabilities, options, and optimizations as research and computational capabilities evolve.

Work performed during FY14 was in three areas: 1) Design, implementation, and user support of the overall ESMF architecture, include the machine representation (Virtual Machine) and Array and Array parallel distribution representations; 2) Design, implementation and user support of NUOPC Layer software and applications; and 3) Design, implementation, and user support of the ESMF Field and Field bundle classes, including a data structure for conservative interpolation called an exchange grid. Improvements to ESMF and NUOPC software in all three areas were delivered in two releases, public release ESMF v6.3.0r (January 31, 2014) and ESMF patch release 6.3.0rp1 (July 14, 2014). Patch releases are minor releases that address specific short-term needs or fixes. In the next section, the specifics of these ESMF releases are discussed. Activities related to application development and user support are described in the section after that. Appendix A includes all improvements made to the ESMF and NUOPC software.

RESULTS

1) ESMF and NUOPC FY14 Releases

The ESMF v6.3.0r release concluded a development cycle that was focused on supporting advanced grid remapping capabilities for a wide variety of applications in modeling and data services, and in producing a production-quality NUOPC Layer. ONR funds support the use of ESMF in multiple ways: 1) to create high-performance, interoperable component-based modeling systems; 2) as a source of data communication, time management, metadata handling, and other libraries; and 3) as a fast, parallel generator of interpolation weights from file for many different grids (see ESMF_RegridWeightGen, https://www.earthsystemcog.org/projects/regridweightgen/). ESMF can also be used in a fourth way, as a Python grid remapping library (this is supported mainly by the NOAA Climate Program Office - see ESMPy, https://www.earthsystemcog.org/projects/esmpy/).

In v6.3.0r, ESMF regridding functions were expanded to include a wider range of grids, interpolation methods, and control options. ESMF now supports during-run and offline grid remapping of unstructured grids composed of polygons with an arbitrary number of sides as well as non-conservative regridding on either cell centers or corners of unstructured grids. The first order conservative

interpolation method was extended to work on 3D grids, and nearest-neighbor interpolation methods were added. There is also a new option to allow the user to select between great circle and Cartesian line paths when calculating interpolation weights on a sphere (note that this was expected for FY15 ONR tasking and was completed early). Grid files that follow the Climate and Forecast (CF) UGRID convention and the CF GRIDSPEC convention are now both supported for various object creation methods and grid remapping. The ESMF_RegridWeightGen application for calculating interpolation weights from file added the option to calculate the interpolation and conservation error for the generated weights for a quick analysis of their quality.

ESMF component software has been extended in a few ways. The component interfaces can support fault-tolerant interactions between components based on a user-controlled "timeout" mechanism, a feature developed in collaboration with the NOAA Global Systems Division. The practical use cases of this feature are large ensemble configurations where individual ensemble members may crash or become unresponsive during the course of a simulation run. Another new component-level feature is the ability to transfer either logically rectangular Grid or unstructured Mesh objects between components that run on different sets of processors. This is useful when implementing coupled systems where a component needs to access fields of another component on that component's native grid.

The NUOPC Layer software was ported to all ESMF supported platforms and thoroughly regression tested. A run-time tool called a “Component Explorer” was added, which can be used to analyze a component’s compliance status. Other additions include support for resolving data dependencies during initialization for components that are running concurrently, and defining a standard way to combine the build systems of different components when coupled together.

The NUOPC Layer improvements and fault tolerance mechanisms are implemented in the v6.3.0r release. There are continued implementations of exchange grids (XGrids). These data objects conserve flux quantities as they pass through the interface between domains (Balaji et al. 2007). The implementation now allows combinations of logically rectangular Grids and unstructured Meshes to be supplied on either side of the XGrid. Weights generated by regridding through the XGrid can be renormalized by user-supplied source or destination area, and area and centroid information can be retrieved.

In public patch release **ESMF v6.3.0rp1**, the ESMF grid remapping utilities were extended as a result of user feedback to offer destination fraction normalization for the conservative interpolation scheme in addition to the regular destination area normalization. Also, the portability of the library was enhanced in several areas: ESMF can now be built with native support for the Intel MIC architecture, the Apple Clang/LLVM C++ compiler is supported on both Linux and Darwin, and ESMF's dependency on the NetCDF C++ interface has been removed to reduce the number of build dependencies.

2) Applications and User Support

The ESMF and NUOPC team interacted with NRL developers on a number of support issues and feature requests in FY14. These interactions included the following:

The ESMF grid remapping lead (Oehmke) organized a call among ESMF development team and NRL scientists to discuss how best to handle unmapped points during grid remapping. This ability to

extrapolate to points that lie outside the source grid is currently scheduled for delivery in release 7.1, during FY15.

Other interactions involved helping NRL scientists to use high order patch interpolation for grid remapping and to identify a suitable pole handling method. Another problem solved was on the NetCDF3 file format when the interpolation weights were in. The weight file was so large that a NetCDF4 format would solve the problem. Other problems solved included a mismatch in coordinate systems, and the grid remapping. One of the improvements in 6.3.0rp1, the removal of the dependency on the NetCDF C++ interface, addressed the porting issue and James was able to get ESMF built on the upgraded system by updating to the new ESMF version.

One interaction resulted in changing ESMF so that it reports a non-zero error code to MPI_Abort calls, which allows scripts that are calling the program to tell that an error occurred. NRL scientists also raised the possibility of ESMF providing a transpose of the regrid/redistribution operations for data assimilation. Other ESMF team actions included fixing a small issue with CPPFLAGS that Tim identified, iterating with him on the best way to support the IBM iDataPlex build, and incorporating contributed code from Tim into the ESMF build which makes it easier for ESMF to find paths for NetCDF4 and its associated HDF dependency.
IMPACT/APPLICATIONS

Interoperability among national operational and development agencies will lead to accelerated advancement of the environmental numerical prediction, better sharing of computing resources and more reliable operational backup. The Guidance Enhancement system will enable Navy production centers to produce the best guidance possible to support forecasts and associated decisions. The products will support improved high wind and seas warnings, and in addition, the enhanced uncertainty products will provide improved guidance for Level 3 forecasters in the *Watch Floor of the Future* construct.

RELATED PROJECTS
6.4 ESPC Coupled Global system, 6.4 NAVGEM.

REFERENCES

Balaji, V., J. Anderson, I. Held, M. Winton, J. Durachta, S. Malyshev, R. Stouffer, The Exchange Grid: a mechanism for data exchange between Earth System components on independent grids, GFDL Technical Note, 2007.

Appendix A: ESMF / NUOPC Improvements for FY14 Releases

ESMF 6.3.0r (January 2014)

- The NUOPC Layer contained in this release has been improved in the following specific technical areas:
- The NUOPC Component Explorer was added. This is a run-time tool that can be used to analyze the compliance status of a Component.
- Standard Component dependencies have been formalized and documented, making Components more interoperable on the build level.
- The resolution of data dependencies during initialization was extended to cover components that run on different petLists.
- The transfer of Grid and Mesh objects between Components is now supported during initialization.
- The tools that allow Components to be made available as web-based services now provide the capability to use a job scheduler to manage the execution and resource allocation for the service.
- The capability to create logically rectangular Grid objects from NetCDF files in SCRIP format was added to ESMPy, the ESMF Python interface. Documentation and downloads are available on the ESMPy web page.
- Distributed objects Fields, Arrays, Grids, and Meshes created in one Component can now be transferred to another Component, even when the Components are defined on different petLists.
- The "--check" option was added to the ESMF_RegridWeightGen application to calculate the interpolation and conservation error from regridding with the weights in the output file. The error is calculated using an analytical test field.
- The ESMF_RegridWeightGen() interface was overloaded to allow regridding between grids with user specified element and optional nodal distribution. The grids must be supplied in the SCRIP format.
- The ESMF_FieldRegridStore() call has been extended to work on Fields built on Meshes containing elements with more than four sides (e.g. pentagons and hexagons).
- The ESMF_FieldRegridStore() call has been extended so that non-conservative interpolation methods (bilinear, patch, and nearest-neighbor) can be performed on Fields built on the Mesh element location (ESMF_MESHLOC_ELEMENT).
- The ESMF_FieldRegridStore() call now allows the user to choose between great circle or Cartesian paths for the line between two points on a sphere during the calculation of bilinear interpolation weights.
- The ESMF_FieldEmptySet() method now allows the Grid, Mesh, LocStream, or XGrid object to be replaced in a partially completed Field.
- The ESMF_MeshCreate() interfaces have been extended to allow the user to specify a coordinate system. This information is used by the ESMF_FieldRegridStore() call to automatically determine the geometry of the source and destination Meshes.
- The ESMF_MeshCreate() and ESMF_MeshAddElements() methods have been extended to allow the user to create a Mesh containing elements with more than four sides (e.g. pentagons and hexagons).

- The ESMF_MeshCreate() and ESMF_MeshAddElements() methods have been extended to allow the user to optionally set element center coordinates. This information is used when doing non-conservative regridding on Fields built on the Mesh element location (ESMF_MESHLOC_ELEMENT).
- The ESMF_MeshCreate() which allows the user to to create a copy of an existing Mesh, but with a different distribution, now allows the user to optionally omit the node distribution.
- The ESMF_MeshCreate() method has been extended to allow generation of the nodal mask when reading from a UGRID file.
- The ESMF_MeshCreate() method has been updated to support the new UGRID version 0.9.0 conventions.
- The ESMF_MeshCreate() method has been extended to allow Meshes to be created from a grid file with user specified element and optional nodal distribution.
- The ESMF_GridCreate() interface was overloaded to allow Grids to be created from a grid file with user specified distribution.
- The ESMF_AttPack type was introduced, allowing a user to retrieve a handle to an ESMF Attribute package. This is a more compact way of working with Attribute packages.
- The ESMF_UtilIOGetCWD() interface was added to allow retrieval of the absolute path and name of the current working directory.
- A new parallel application ESMF_Scrip2Unstruct was added to convert a SCRIP format grid file to an unstructured ESMF format or a UGRID format grid file. This allows the user to execute the potentially expensive file format conversion operation once instead of every time the ESMF_RegridWeightGen application is called. The SCRIP file can be either unstructured or logically rectangular. The application has an option to generate a dual mesh, which is needed to support non-conservative regridding on cell centers. regridding, and numerical results of some specific test cases.

ESMF 6.3.0rp1 (July 2014)

- An optional command line argument "--no_log" was added to the ESMF_RegridWeightGen application. This allows the user to turn off the ESMF log files that are written by default.
- The ESMF regrid weight generation system now allows the user to choose between two normalization types when generating conservative interpolation weights: destination area normalization (default) and destination fraction normalization.
- The ESMF Python interface (ESMPy) is now part of the ESMF source distribution. The build and installation process for both ESMF and ESMPy remain separate in this release.
- When building ESMF with NetCDF support enabled, the NetCDF C++ interface is no longer required.
- New build configurations were added to support the Apple Clang/LLVM C++ compiler on both Linux and Darwin systems.
- Support was added to compile the ESMF library for the Intel MIC architecture under Linux. This allows ESMF applications to execute natively on the Intel Xeon Phi accelerator hardware.